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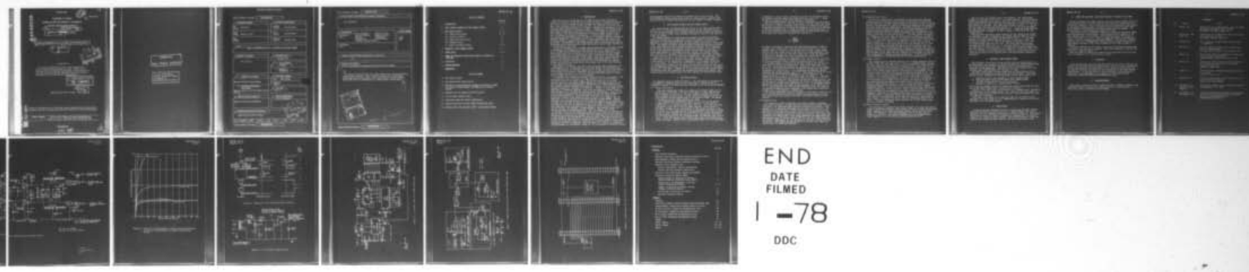

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(10) W.H. Jolley

S U M M A R Y

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1. INTRODUCTION

The timing circuit associated with the WRE strand burner, described in reference 1, has been in use here for a number of years. Basically the method uses two fuse wires threaded through the propellant strand a known distance apart, both carrying a small electric current. As each wire is fused in turn by the flame front passing across it a voltage is transmitted successively to the start and stop inputs of an electronic timer. Problems with the timing circuit have always been present, resulting in the loss, on average, of one result in about twenty. This failure rate has not been serious enough to warrant more than the occasional cursory investigation. In recent years, however, this problem has been exacerbated with the burning of increased numbers of strands of composite propellant. For reasons not yet fully understood, the failure rate with some types of composite propellant is much higher than with double base propellant. Inadequacies in the timing circuit have also shown up when used in conjunction with a recently constructed high pressure strand burner resulting in an unacceptable failure rate.

In the "low pressure" (up to 20 MPa) strand burner(ref.2), propellant strands are burned in an atmosphere of nitrogen gas whereas in the "high pressure" (up to 70 MPa) strand burner(ref.3) the strands are burned under water. The usual faults which lead to failure of the timing circuit are greatly enhanced by the water medium in the high pressure bomb. Such faults are common mode problems (arising mainly because of the common earth lead), shorting across the timing wire terminals, spurious voltage spikes originating usually from the action of the igniter wire portion of the circuit or sometimes from unknown sources along the mains, small and/or noisy signals due to non-clean breaking of the timing wires etc.

These faults, and others, can lead to the electronic timer receiving a stop signal before, or at the same time as, the start signal, thus preventing the timer from starting; or the start signal may be too small to switch the timer on or too noisy to be accurate. Similarly the stop signal may be insufficient to stop the timer counting or too noisy to produce an accurate result or it may operate prematurely thus giving a false reading.

To overcome these problems alternative timing methods were considered. Some innovations have been introduced in timing systems in other establishments throughout the world in recent years. The two main ones are the acoustic emission technique, developed at AFRPL Edwards Air Force Base (refs.4,5), and the microwave technique implemented at RPE Westcott and elsewhere(refs.6,7). The acoustic emission technique shows promise of being a real technical advance, combining simplicity, accuracy and reliability. However it would appear to be applicable to composite propellant only since the signal is probably derived from the fracture of the oxidiser crystals during deflagration. It is not yet known whether a characteristic acoustic signal is emitted during combustion of cordite-type propellants. In the microwave technique, the value of the dielectric constant of the propellant must be known, and it appears that the measurement of this quantity to sufficient accuracy is troublesome. Another technique which depends directly on the dielectric constant of the propellant, although its value need not be known, has been developed by Hermance(ref.8) but the complexity and lack of precision of the method, make it unfavourable. Other techniques which have been employed for measuring strand burning rates include optical methods - photographic, cinephotographic, photoelectric sensors etc. - and various pressure measuring methods. (See for example, refs.9,10).

Considering that any new method would take time to develop and implement at WRE and that the need for an improved system was urgent, and also that present facilities and procedures are designed for the traditional fuse wire technique, it was decided to try and improve the existing system. This has resulted in a circuit which has been based on the same principle as the previous one but which is able to conveniently treat and condition the incoming signals by using modern integrated electronic components. This has meant that there are no changes in test procedures and only minimal changes to the instrumentation hardware involved.

This memorandum describes in detail the circuit that has been evolved. The fully assembled timing console which houses the timing circuit, together with several ancillary circuits described later in this report, is shown in figure 1.

2. BASIC DESIGN CRITERIA FOR THE TIMING CIRCUIT

As outlined above, the main reasons for failure of the timing circuit were found to be, (i) spurious signals (usually spikes) on the stop input line to the timer occurring before or at the same time as the start signal was received, or (ii) too small a signal being received at either the start or stop input to switch the counter.

To overcome problem (i), some means was required of preventing spurious signals from reaching the counter before the start signal was received and/or some means of discriminating between a spurious signal and a genuine one. Problem (ii) arises principally with the high pressure bomb which is filled with water. The gaseous combustion products evolved during burning readily dissolve in the water creating a fairly strong electrolyte solution. This conducting medium lowers the resistance between the fuse wire terminals to as little as 20 ohm which drastically degrades the signal received when the wire fuses. A simple amplification of the signal would not overcome this problem because these circuits are inherently "noisy" and the degraded signals from the stop and start wires can be of the same order of magnitude as the background "noise".

Another fact to note is that the time interval meter previously used, an Eldorado Model 255, had two discrete input level settings. This created a problem because of the variability in degradation of the signals coming from the strand burner. To overcome this difficulty a trigger circuit has been incorporated which operates on any signal received that is above the bias level, set just above the noise level, and delivers a clean output pulse of an appropriate level to the timer. Towards the end of development of this timing circuit the Eldorado timer was replaced by one designed and constructed locally. For similar reasons the trigger circuit was still required for use with this timer.

3. THE TIMING CIRCUIT

The complete circuit is given in figure 2. For the purpose of discussion it is convenient to consider the circuit as consisting of several parts, as indicated in figure 2, and these are each discussed in the following sub-sections.

3.1 Timing wire circuit

The basic operational method is to apply a d.c. voltage to each wire in series with a resistance. The series resistance is large compared with the resistance of the wire, so that the voltage drop across the timing wire is negligibly small until it fuses, when the voltage drop across the wire terminals ideally becomes equal to the applied voltage. The change in voltage as the wire fuses activates the timer.

Two considerations are necessary here: (i) the value of the applied voltage, and (ii) the value of the series resistor. In the previous circuit(ref.1), the applied voltage was + 160 V d.c. This value now seems unnecessarily high, and if only for safety reasons, a lower value is desirable. Because of the incorporation of the "trigger circuit" in the new circuit, a low voltage can easily be accommodated. The series resistor, R, must be large compared with the resistance of the timing wire (which is negligibly small so almost any value for R would satisfy this condition) yet not large compared to the resistance across the terminals when the wire fuses. In the low pressure bomb a virtual open circuit is created when a timing wire fuses. However in the high pressure bomb, with its water medium

contaminated to form a strong electrolyte solution, the resistance across the terminals when the timing wire fuses can be as low as 10 Ω . Hence the value of R should not be large compared to this value.

Both the applied voltage, E_S, and the series resistance, R, are related by the circuit current, I. Since this current, I, flows through the timing wire as well, it must be limited so that it does not cause the timing wire to become sufficiently hot to ignite the propellant in which it is embedded. It has been determined that a current of 100 mA is quite satisfactory. If R_T is the resistance across the terminals after the timing wire has fused, the voltage drop across the terminals, E_T, is given by:

$$E_T = \frac{R_T E_S I}{E_S + I R_T} \quad (1)$$

In figure 3 a series of curves has been plotted giving values of E_T as a function of E_S. These curves were calculated from equation (1) using a constant value of 100 mA for I and various values for R_T. These curves show (i) that for a given value of E_S, there is a strong dependence of E_T on the value of R_T, and (ii) that for a given value of R_T, E_T approaches a maximum value asymptotically with increasing E_S. Taking the most unfavourable case likely to be encountered, viz. when R_T = 10 Ω , it can be seen that E_T approaches its asymptotic value very quickly so that there is little advantage in using values of E_S greater than 10 V. Since a + 5 V d.c. power supply is required for the other parts of the circuit this could also be used for the timing wires. Then in the worst case with R_T = 10 Ω , the voltage drop across the terminals is 0.83 V, for a current of 100 mA. To obtain the current of 100 mA would require that the series resistor have a value of 50 Ω . But considering the resistors readily available, the nearest suitable one is 47 Ω which gives a current of 106 mA and a voltage drop across the terminals of 0.87 V (compared to its asymptotic value of 1.06 V) for the worst case (see figure 3). This value is well above the background noise level (which can be up to 0.2 V) and high enough to operate the timer reliably through the trigger circuit. One further point to consider in determining the value of the applied voltage, E_S, is that the voltage signal applied to the LM 311 in the trigger circuit must not be higher than its supply voltage (maximum + 15 V) which here is + 5 V. Hence, because of all the factors considered above, the values of the applied voltage and series resistance in the timing wire circuit were chosen to be + 5 V d.c. and 47 Ω respectively.

One further modification made to this part of the previous circuit is the use of shielded wires for the leads between the timing console and bomb. This should reduce any potential or actual "cross-talk" problems in this section.

3.2 Ignition circuit

The propellant strand is ignited in the pressure vessel by passing a large current through a nichrome resistance wire threaded through the end of the strand. The previously used circuit is basically satisfactory. This employs a 6.3 V step-down transformer with an output rating of 15 A. Two modifications have been made. A high rating (100 V, 12 A) silicon diode, MR 1121, has been placed in the line to act as a half wave rectifier. This eliminates the positive component of the a.c. which used to cause common mode problems on the timing wires. Some series resistance and capacitance have been placed across the ignition switch (SW 2) to act as a "spark quencher". An additional capacitance has been placed after the switch between the line and ground. This further reduces the amount of induced e.m.f. which has been a source of common mode problems.

3.3 Continuity test circuit

The previous timing circuit incorporated a test circuit for checking continuity in the timing wire circuit after the wired strand burner head had been placed in the bomb. This utilised an ohm-meter. In the new timing circuit it is more useful to monitor continuity by measuring the voltage on each line coming from the timing wires. Provided continuity is sufficient to result in the voltage at the input to the voltage comparator, LM 311, being less than the threshold voltage the circuit will be operative. In practice this means that the contact resistance of the timing wires at the terminal posts must be less than about 5 Ω . The means chosen to measure the voltages on the input lines, and hence monitor continuity, has been to use a light emitting diode (LED) at the output of each voltage comparator, LM 311. If the output is low (i.e. a logic "0") the LED will be on; if the output is high (i.e. a logic "1") the LED will be off. Thus as long as there is continuity in the timing wires circuit the LED will be on. This method of monitoring continuity represents an obvious advance over the previous circuit where the operator had to switch in and then check each wire individually. A further advantage of using this technique is that the operator has a visual check that the timing system is working by observing that the LED's on the start and stop lines go out at the same time that the timer commences and finishes counting respectively. A LED has similarly been incorporated in the ignition circuit for checking continuity.

3.4 Trigger circuit

The "trigger circuit" consists basically of a voltage comparator (LM 311) in each of the start and stop lines. + 5 V is a convenient supply voltage for these chips and this, then, is the nominal level of the output when the threshold voltage has been exceeded on the input line. Thus, even if the input signal coming from the timing wires is degraded and "ragged" (as it often is) the output signal which is transmitted to the remainder of the circuit is clean, sharp and of constant and adequate strength (5 V). The threshold level of the voltage comparators can be adjusted by means of the variable 1 k Ω resistors on pin 4. It has been found that a threshold voltage of 0.2 V is satisfactory in each line. This value is influenced by the "disconnect" diode, 1N914, which is placed just ahead of the LM 311. This diode prevents any signal on the input line of less than + 0.6 V (nominal) from reaching the LM 311. Thus it stops the negative common mode voltage generated by the ignition circuit and also most of the general background "noise". It also acts as a voltage level shifter, reducing any voltage greater than + 0.6 V by 0.6 V. Hence a minimum voltage of + 0.8 V must be generated by the breaking of the timing wires for the circuit to be triggered. This will be the case provided there is at least 9 Ω across the terminals when the timing wire breaks, and this corresponds to the worst case likely to be encountered. As an added precaution in conditioning the input signal, a low pass RC filter has been put immediately ahead of the LM 311. This is to remove any "hash" generated by the push button ignite switch as it makes and breaks.

3.5 Spike eliminator circuit

The function of this part of the overall circuit is to cause any spurious spikes to be ignored, whatever their origins, while at the same time allowing normal operation of the timer for genuine signals coming from the timing wires. The operation of the spike eliminator circuit is best seen by reference to figure 4. This shows diagrammatically what happens when a signal appears on the line from the voltage comparator LM 311.

Case (a) shows the situation when a spike appears. The leading edge triggers the monostable which has a 1.4 ms delay function. The hex-inverter delays the appearance of the spike at the gate input by approximately 125 ns. This ensures that the gate input from the monostable is a logic "0" when the spike arrives at the gate. The output from the gate is thus a "1". By the time the output from the monostable returns to a "1", the spike has passed and thus again the output from the gate is a "1". Hence the output from the following inverter is always a "0" and no signal is received by the time interval meter.

Case (b) shows that when a genuine signal from the timing wires arrives, the monostable is again triggered by the leading edge and again the output from the hex-inverter is delayed by approximately 125 ns. In this case, however, the signal remains high (as it is not a spike) and so when the monostable returns to a "1", each of the inputs to the gate is a "1" and so the gate output then falls to a "0". The output from the following inverter thus goes from a "0" to a "1" and this signal is transmitted to the timer which is then activated. It is noted that the signal originating from the breaking of the timing wire is delayed by a little more than 1.4 ms before it reaches the time interval meter. However the same delay occurs with both the start and stop signals and so the time interval measured is unaltered.

4. ELECTRONIC TIME INTERVAL METER

The electronic time interval meter now used with the strand burner is a general purpose one, designed and used within Combustion and Explosives Group. It is TTL compatible and hence completely suited to the timing circuit described in this Memorandum. (The timing circuit was developed while the previous timer, Eldorado Model 255, was still in use).

The time interval meter consists essentially of three printed circuit boards which are mounted in a rack inside the timing console. These three printed circuit boards and the drawing numbers giving their circuits are:

1. crystal oscillator clock generator, drawing number PD 8303;
2. 8-bit BCD counter latch and tri-state card, drawing number PD 8306 (being used here as a 5-bit counter);
3. decoder and readout unit, drawing number PD 8155.

The interwiring diagram showing the connections between these cards for their use as the strand burner timer is given here as figure 8.

Display of the timer output is by means of five 7-segment LED's, mounted on the front panel of the timing console. Also located on the front panel is a LED which indicates the status of the timer gate, and hence whether the timer is in the reset condition.

Since each of the cards constituting the timer has an on-card voltage regulator, the power supply to it is unregulated and is drawn from the circuit described in the following section.

5. POWER SUPPLY

A single step-down transformer is used to provide all the power requirements for the various circuits housed in the timing console. The circuit diagram of the +5 V regulated power supply is shown on figure 5. With component values as shown the output is adequate for supplying all +5 V supplies needed by the timing and other circuits. Also shown on figure 5 is the tapping for the unregulated supply taken to the time interval meter cards.

6. TIMER FOR MEASURING CONDITIONING PERIOD OF STRANDS IN THE BOMB

Current procedures for strand burning (in the low pressure bomb) call for a conditioning period of 5 minutes from the time the bomb is pressurised till the strand is ignited. This is principally to allow temperature stabilisation. In the previous timing system, a 5 minute electric timer (the Venner timer - see reference 1) was mounted in the timing console for this purpose. For various reasons it was desirable to replace this unit.

A new timer has been constructed, based on an externally adjustable square wave oscillator and binary counter. A BCD decoder allows selection of the time interval, from 1 to 9 minutes. Visual display of the time status is given in two ways: (i) a pair of LED's is used, one (WAIT) to indicate that timing is still in progress and the other (READY) to indicate that timing is complete, and (ii) a 7-segment LED indicator gives a digital display of the time elapsed in minutes. The circuit diagram for this timer is given in figure 6.

A further indicator for this timer is an audible alarm which operates when the measured time interval is complete. The circuit diagram for this audible indicator is shown in figure 7.

This new timer for strand conditioning and its associated indicators have been incorporated in the console shown in figure 1.

7. CONCLUSION

A new timing circuit has been described which can be used for both the low pressure and the high pressure strand burners. This new circuit overcomes all the problems which had been associated with the previous timing circuit and the many new problems associated with the introduction of the high pressure strand burner. It has been found to operate reliably and accurately and represents a real improvement in the operation of the strand burning facilities provided by Combustion and Explosives Group.

8. ACKNOWLEDGEMENTS

The helpful assistance of Mr F. Rousseau and Mr D. Graham of Combustion and Explosives Group in designing the timing circuit and in providing the ancillary circuits is gratefully acknowledged.

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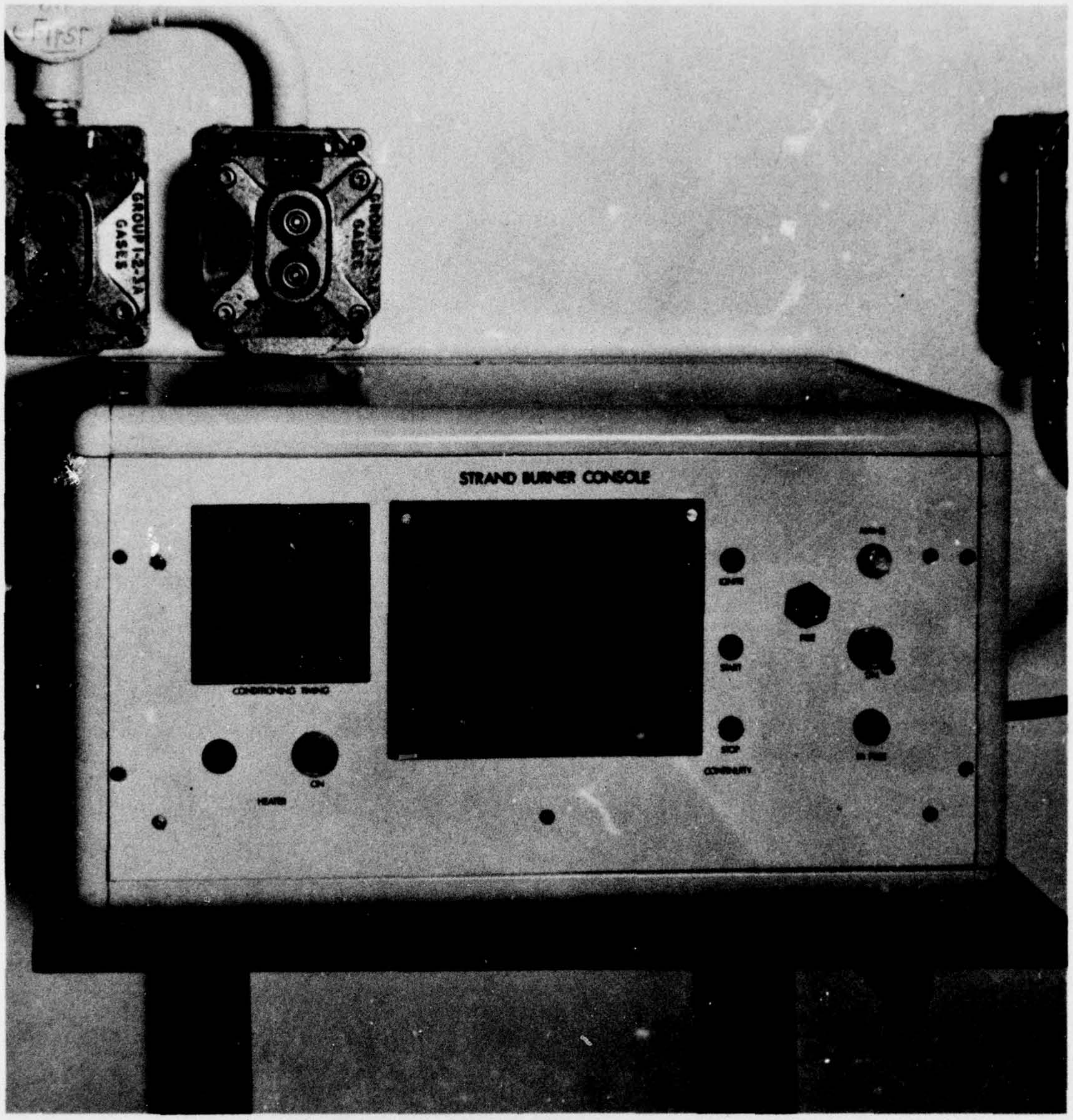


Figure 1. The timing console

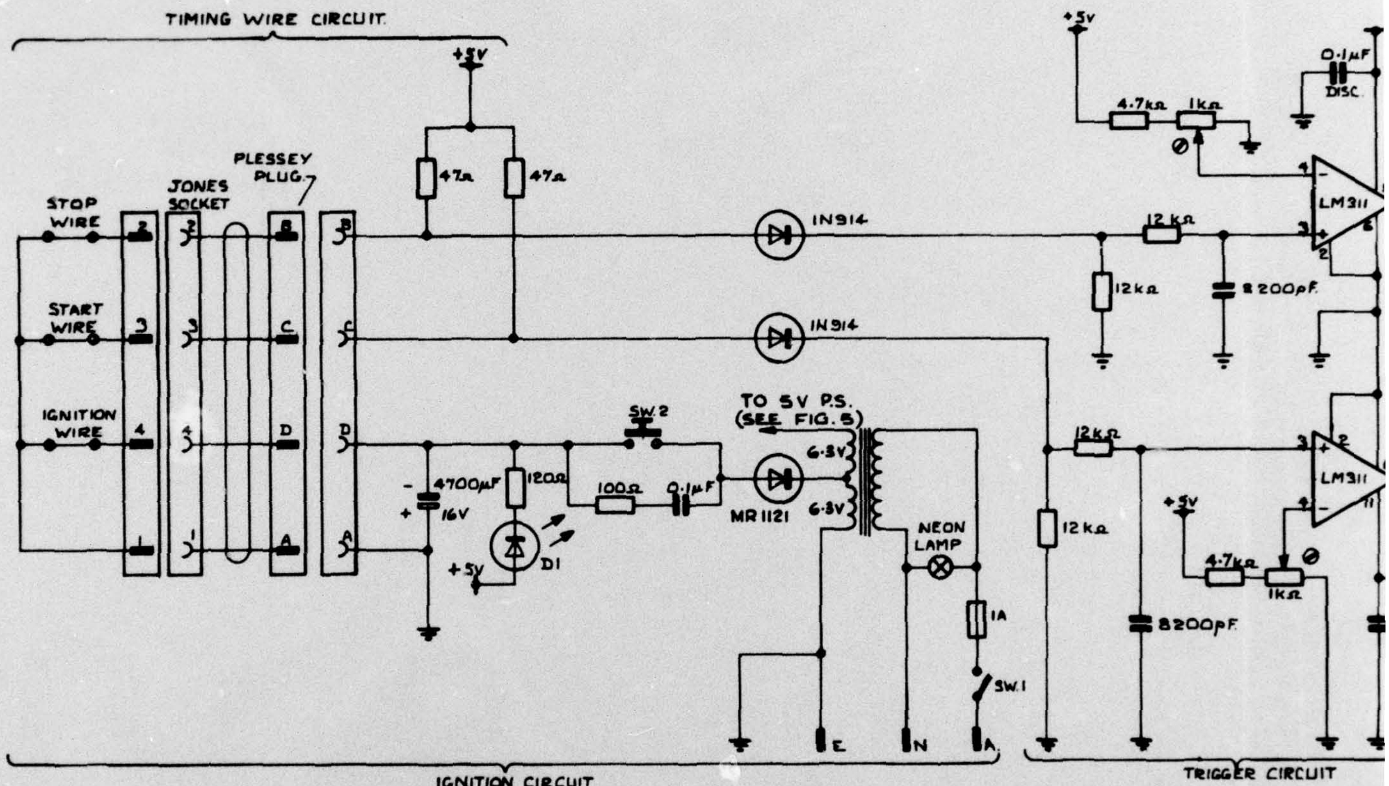
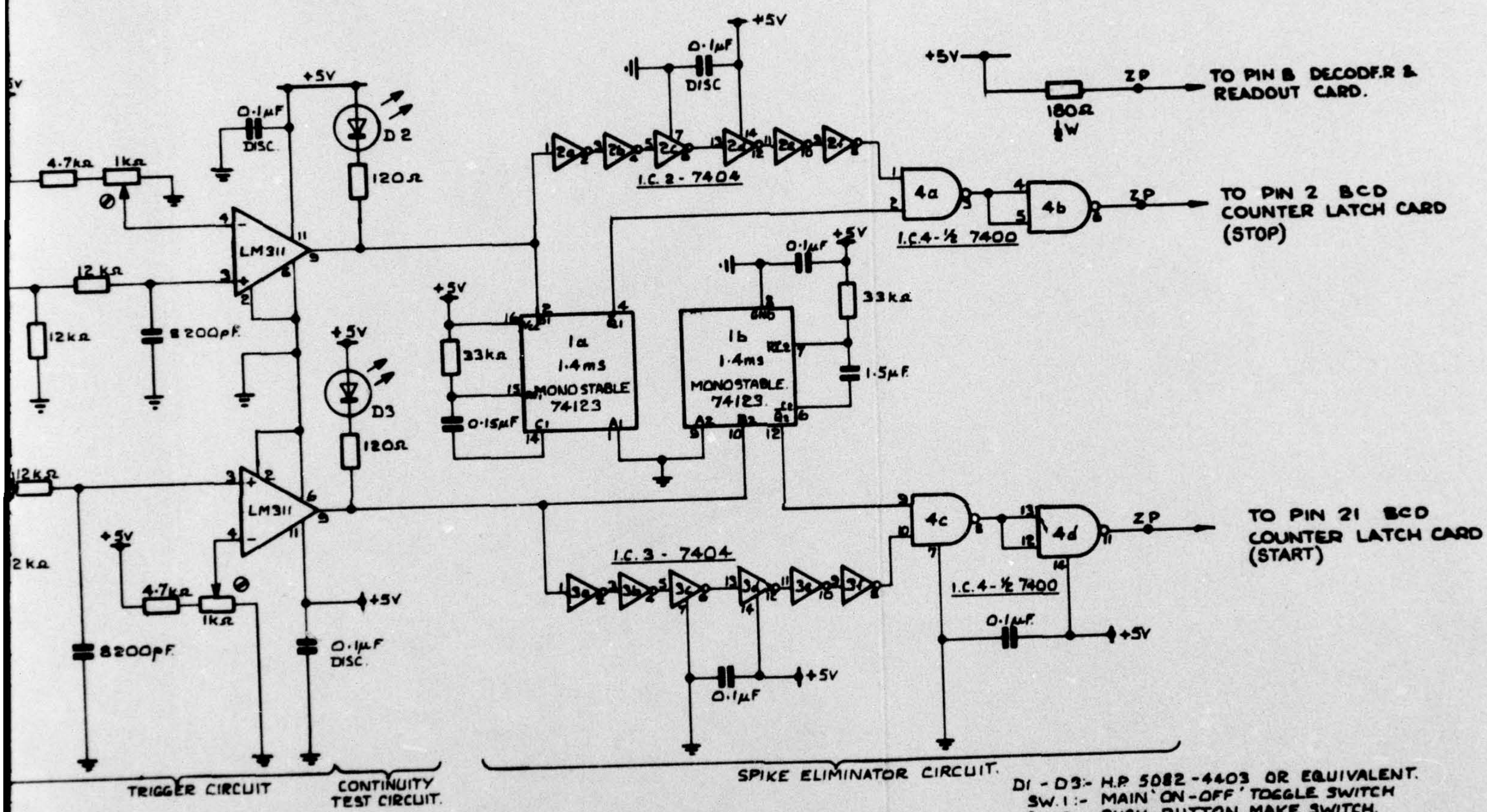


Figure 2: The ignition an



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for any future modifications

ure 2: The ignition and timing circuit

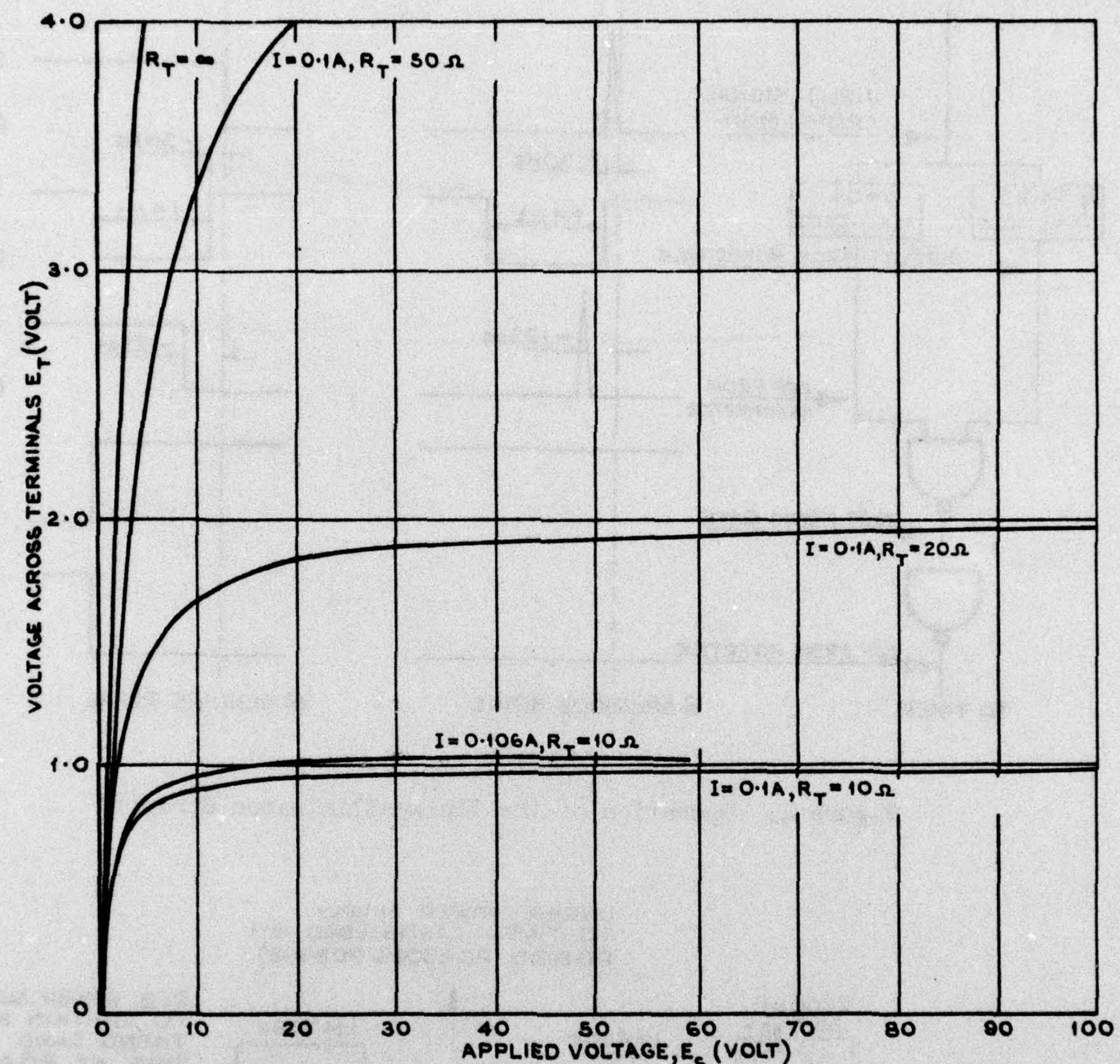

Figure 3. Variation of across-terminal voltage with applied voltage for various across-terminal resistances and constant current

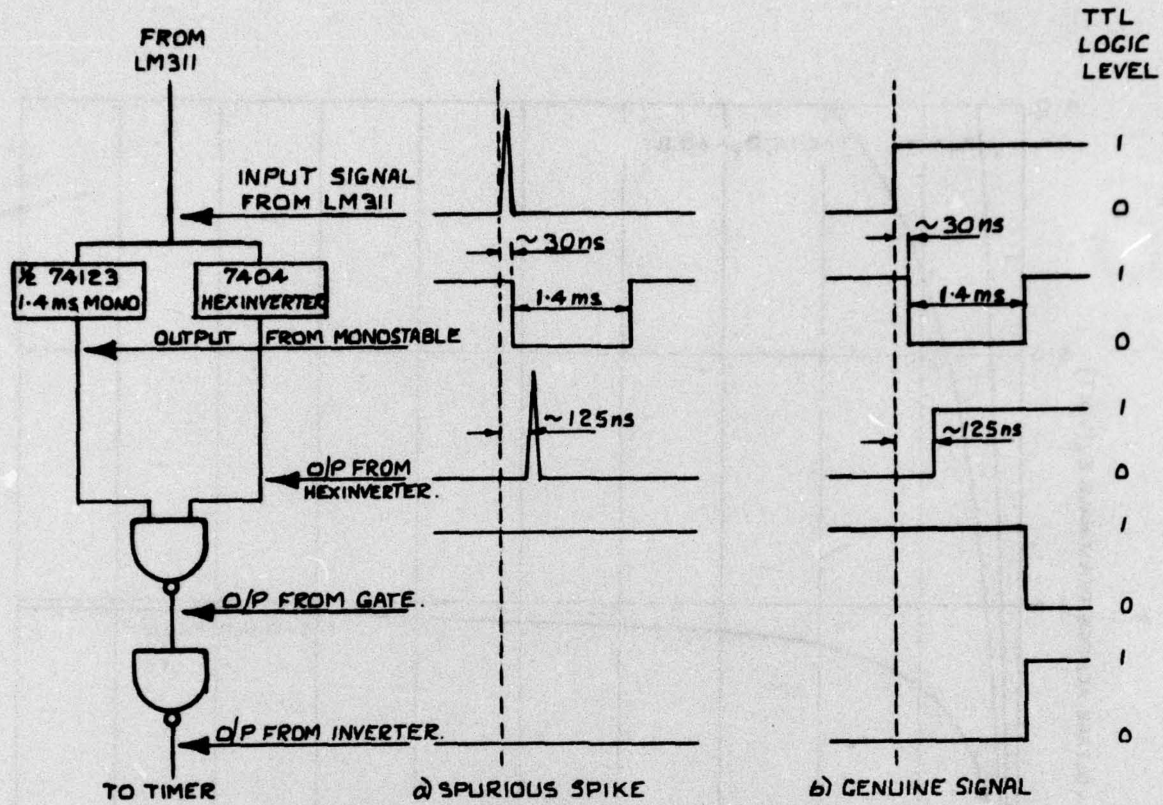

Figure 4. Operation of the "Spike Eliminator Circuit"

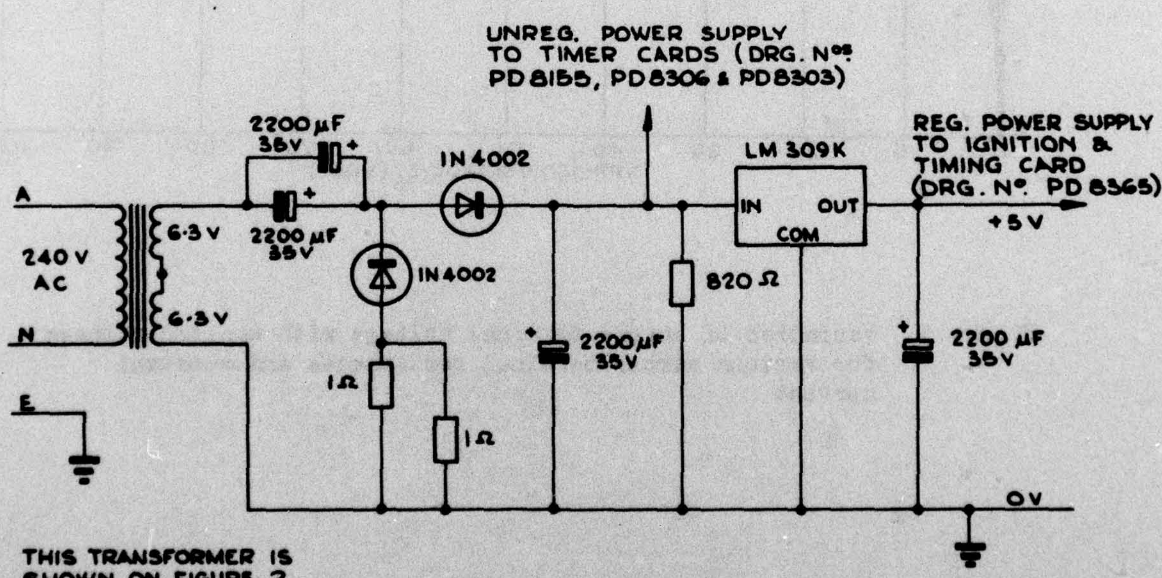

Figure 5. +5 volt power supply circuit

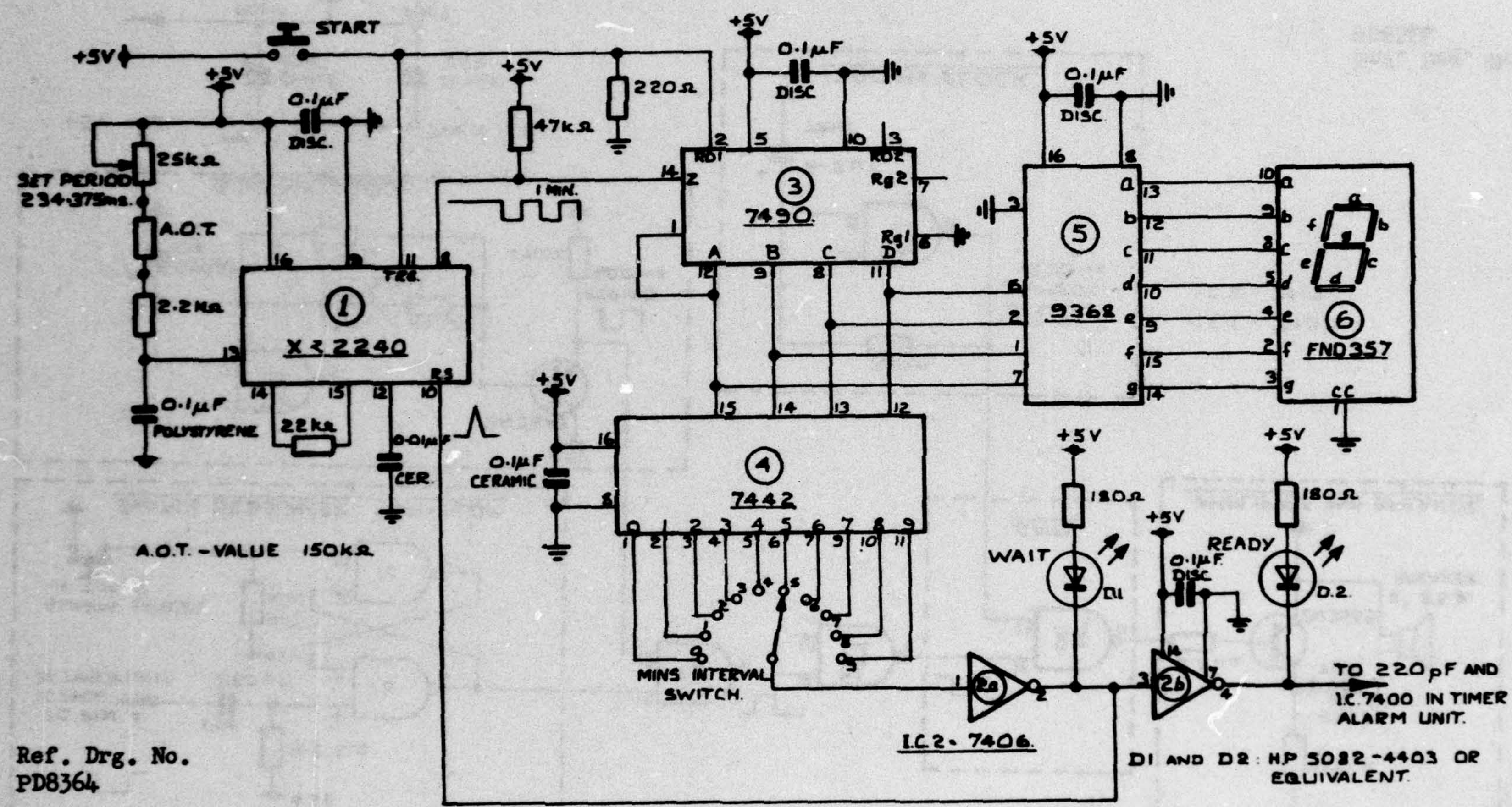

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Figure 6. 0-9 minute timer for strand conditioning

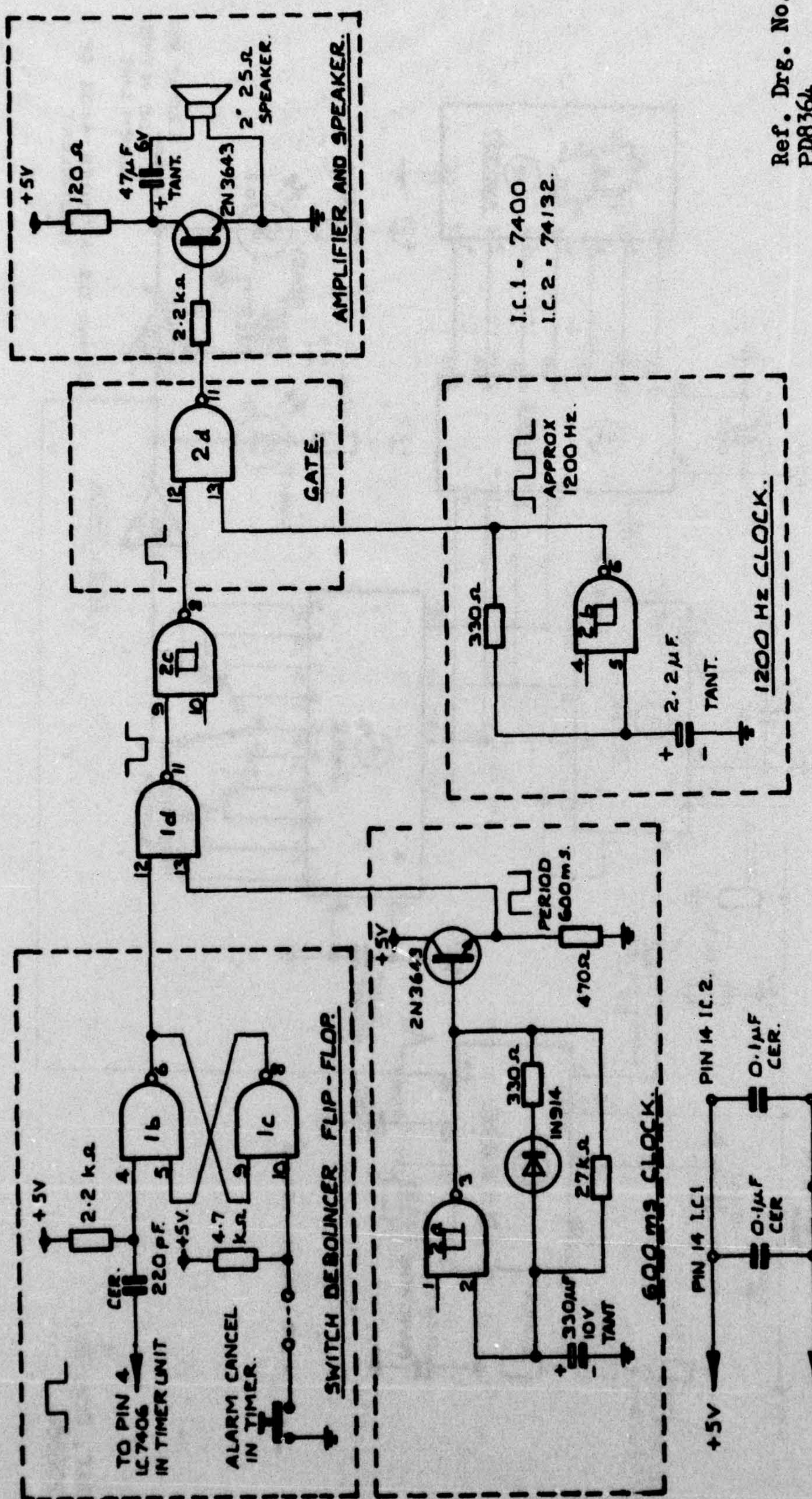

Figure 7. Audible alarm for use with strand conditioning timer

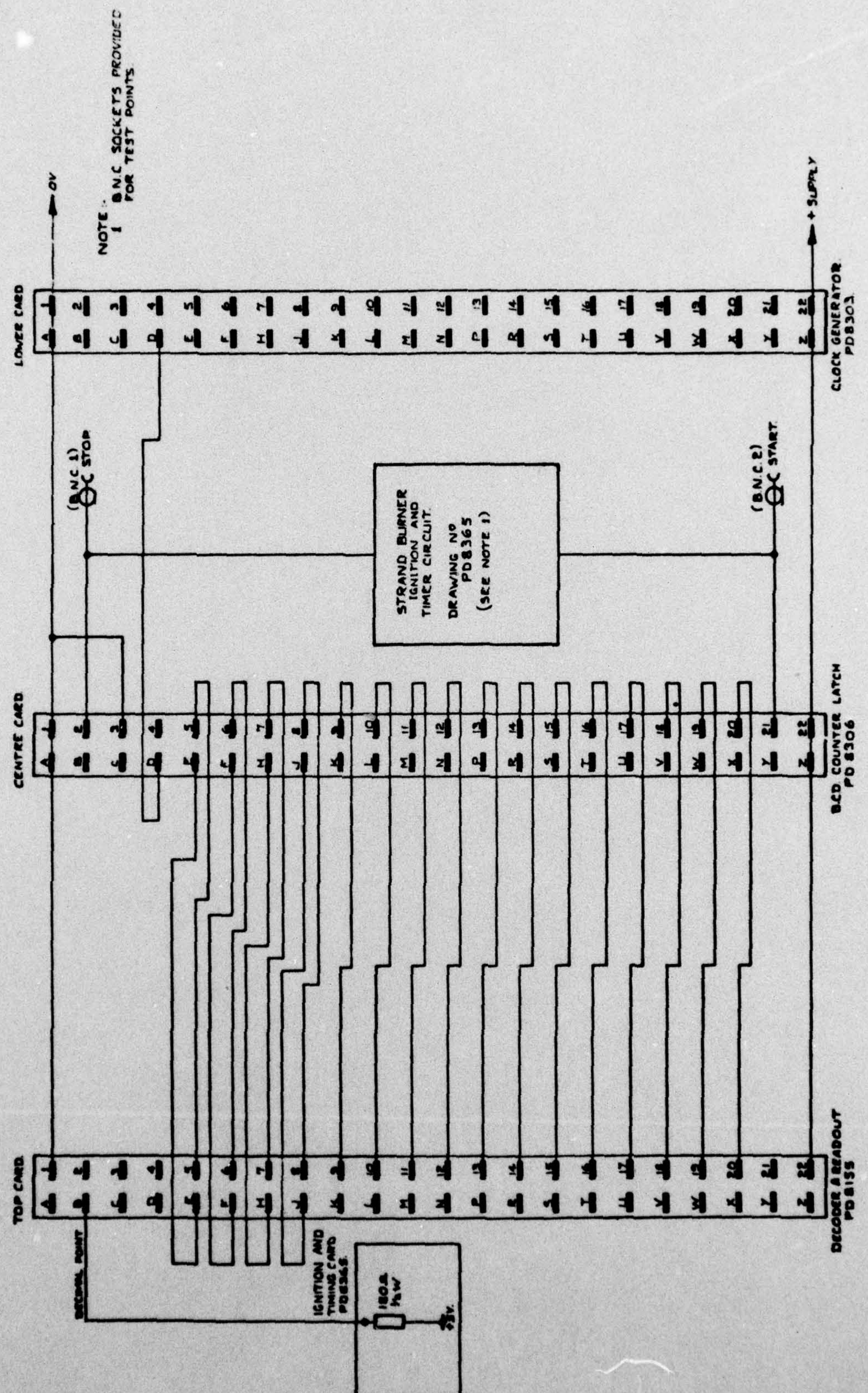

Figure 8. Strand burner time interval meter - interwiring diagram

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